Published in final edited form as:
Acta Paediatr. 2005 September ; 94(9): 1266–1272.

Does the choice of bottle nipple affect the oral feeding performance of very-low-birthweight (VLBW) infants?

C. E. SCHEEL[1], **RICHARD J. SCHANLER**[2], and **CHANTAL LAU**[1]

1 *Department of Pediatrics, Section of Neonatology, Baylor College of Medicine, Houston, TX, USA*

2 *Division of Neonatal-Perinatal Medicine, Schneider Children's Hospital at North Shore, North Shore University Hospital, Manhasset, NY, USA*

Abstract

Background—There is a continuous debate regarding the best bottle nipple to be used to enhance the bottle-feeding performance of a preterm infant.

Aim—To verify that feeding performance can be improved by using the bottle nipple with the physical characteristics that enhance infants' sucking skills.

Methods—Ten "healthy" VLBW infants (941±273 g) were recruited. Feeding performance was monitored at two time periods, when taking 1–2 and 6–8 oral feedings/d. At each time and within 24 h, performance was monitored using three different bottle nipples offered in a randomized order. Rate of milk transfer (ml/min) was the primary outcome measure. The sucking skills monitored comprised stage of sucking, suction amplitude, and duration of the generated negative intraoral suction pressure.

Results—At both times, infants demonstrated a similar rate of milk transfer among all three nipples. However, the stage of sucking, suction amplitude, and duration of the generated suction were significantly different between nipples at 1–2, but not 6–8 oral feedings/d.

Conclusion—We did not identify a particular bottle nipple that enhanced bottle feeding in healthy VLBW infants. Based on the notion that afferent sensory feedback may allow infants to adapt to changing conditions, we speculate that infants can modify their sucking skills in order to maintain a rate of milk transfer that is appropriate with the level of suck-swallow-breathe coordination achieved at a particular time. Therefore, it is proposed that caretakers should be more concerned over monitoring the coordination of suck-swallow-breathe than over the selection of bottle nipples.

Keywords

Prematurity; bottle feeding; bottle nipple types; sucking skills

Introduction

The recommendations of the American Academy of Pediatrics for the hospital discharge of very-low-birthweight (VLBW) infants include "competent breast or bottle-feeding without cardiorespiratory compromise" [1]. This may be difficult to achieve for VLBW infants because they often have difficulties transitioning from tube to independent oral feedings, i.e., 8 breast and/or bottle feedings/d [2]. However, economic incentives necessitate hospital discharge at the earliest possible time. Insofar as attainment of independent oral feeding is correlated with

Correspondence: Chantal Lau, Department of Pediatrics/Neonatology, Baylor College of Medicine, One Baylor Plaza, Houston, TX 77030, USA. Tel: +1 832 826 1384. Fax: +1 832 825 2799. E-mail: clau@bcm.edu.

earlier hospital discharge [3], it is important to examine whether transition from tube to oral feeding can be accelerated.

Feeding difficulties arise primarily from the infant's own immaturity. Oral motor competence of VLBW infants matures over time [2,4]. This is illustrated by the recent development of a sucking scale for preterm infants born between 26 and 29 wk gestation [2]. The ability to feed orally can be affected by external factors, such as the type of bottle nipple and bottle used [5–8], fluid type and viscosity [9], the infant's behavioral state [10], decreased endurance, and/or caretakers' feeding approach. Little information, however, is available on the extent by which these external factors affect oral motor performance. As such, caretakers will routinely try different approaches, e.g., varying the bottle nipples and/or bottles used, in an attempt to accelerate the transition from tube to oral feeding of these infants.

This study focused on the effectiveness of different bottle nipple types in improving the oral feeding performance of VLBW infants. This interest is based on the fact that there is a continuous debate among healthcare professionals regarding the best bottle nipple to use for a particular infant. Indeed, the physical characteristics, such as size, shape, diameter of nipple hole, and softness (collapsibility) of a bottle nipple may affect the infants' oral feeding performance [9]. Thus, the goal of this investigation was to compare how three different types of bottle nipples, commonly used in nurseries, affect the oral feeding performance of VLBW infants as they mature. We hypothesized that such performance, at a particular time, can be improved by the use of the bottle nipple with the physical characteristics that will enhance the sucking skills, e.g., stage of sucking and suction amplitude, that the infant has developed at that particular time.

Methods

Subjects

Very-low-birthweight infants were recruited from the neonatal nurseries at Texas Children's Hospital (Houston, TX, USA). Those with the following conditions were excluded: major congenital anomalies, infections, hypoxic-ischemic encephalopathy, grades III and IV intraventricular hemorrhage [11], hydrocephalus, or oxygen requirement greater than ¼ l by nasal cannula. The introduction and advancement of oral feeding were left to the discretion of the attending physicians. Ten infants were recruited (6 females, 4 males). Their birthweight averaged 941±273 g (mean±SD). They were born between 24 and 29 wk gestational age (27 ±2 wk), as determined by maternal dates and antenatal ultrasonography. The racial/ethnic distribution was 5:3:2 (Caucasian: African-American: Hispanic). The protocol was approved by the Institutional Review Board for Human Subject Research for Baylor College of Medicine and Affiliated Hospitals. Informed consent was obtained from the parents and the attending physician.

Study design

Oral feeding performance was monitored longitudinally at two time periods: when infants were taking 1–2 and 6–8 oral feedings per day. At each time period and within 24 h, three feedings, each using a different nipple, were monitored. Three commonly used nipples in the United States were evaluated: nipple A (Similac Premature Nipple, Ross Laboratories, Columbus, OH), nipple B (Enfamil Premature Nipple, Mead Johnson, Evansville, IN) and nipple C (Similac Infant Nipple, Ross Laboratories, Columbus, OH). Table I summarizes their specific physical characteristics as provided by the respective suppliers. We have also verified that the manufacturing process of the nipples has not changed over the last 7 y. The relative flow rates presented in the table are based on the actual flow rate calculated by Mathew using a mechanical system that applied a predetermined suction pressure pulse (−60 to −120 cm H_2O) at a fixed rate of 40 pulses/min [5]. A blind assessment of the “relative softness” of the nipples was conducted by one of the investigators (CES) using empty nipples. For the duration of the study, the subjects were randomized to one of six possible sequences in which the three nipples could be used. To ensure that the study did not interfere with the infant’s opportunity to breastfeed, the monitored feedings were carried out only in the absence of the mother. Insofar as volume and fluid types and viscosities can affect flow rate, within each 24-h period, the same type and volume of milk that infants received routinely was offered [12]. As behavioral states [13] and fatigue affect oral feeding performance, care was taken to ensure that infants were not disturbed 30 min before each test. In order to eliminate variation due to different feeding methods, the same investigator (CES) fed all the subjects. If present, orogastric tubes were removed prior to the feeding. To monitor the true performance of the infants, no encouragement was given during the monitored sessions, i.e., the infants were allowed to feed at their own pace. If the infant did not finish the prescribed volume in 20 min, the remaining milk was given by naso- or orogastric tube. To assess the volume consumed, the bottle was weighed at the beginning and at the end of the feeding. Any milk leakage during the feeding sessions was monitored by weighing the bib pre- and post-feeding. Milk density being ~1.01 kg/l, 1 g was equated to 1 ml.

Outcome measures

The rate of milk transfer for the total duration of the feeding (ml/min, volume consumed over duration of an entire feeding) was used as the primary outcome of the oral feeding performance of the infants. Percent overall transfer (percent of volume transferred during an entire feeding/ total volume of milk ordered for that feeding) was also monitored as it is one of the clinical measures on which progression of oral feeding is based. The duration of a feeding included the “out” times when the infants needed to burp, cough, and/or rest. The duration of these “out” times was left to the discretion of the investigator (CES) who assessed when the infant needed to stop and was ready to feed again. In our opinion, this provided a more accurate measure of the *actual* performance of the infant.

Prior to each monitored feeding, the bedside nurse was asked her choice of bottle nipple if she were to feed the infant. The percent agreement between caretakers’ nipple selection and the one providing the optimal rate of milk transfer at each feeding was calculated as follows: number of times caretakers’ choice of nipple matched the one providing the optimal milk transfer over the total number of assessments conducted multiplied by 100. The behavioral states of the infant as defined by the Neonatal Individualized Developmental Care and Assessment Program [NIDCAP] [13,14] were measured from the start of the feeding and approximately every 5 min by the same investigator (CES) during the feedings. From these, an average behavioral state was computed for each feeding session. Oxygen desaturation, defined as oxygen saturation <88% for any length of time, was noted during all the assessments.

To measure specific features of an infant’s sucking, we used the same monitoring device described in our earlier studies [15,16] with the following modification. The suction component which measures the negative intraoral pressure was monitored via a Mikro-tip sensor transducer (Model SPR-524, Millar Instr., Houston, TX) inserted flush to the tip of the nipple without protruding into the infants’ mouth. The use of such a pressure-sensing tip catheter negated the potential dampening of the pressure waveform during feeding. The expression component which measures the positive pressure generated by the compression/stripping of the nipple was measured through a Silastic/polyethylene tubing connected to a pressure transducer (Gould P23, Astro-Med Inc., Boston, MA). Such a set-up allowed for the simultaneous recording of the suction and expression/compression components of sucking (Figure 1). Data were recorded onto a MP100 Biopac System (Biopac Inc., Santa Barbara, CA) and analyzed using the Biopac Acknowledge software program.

The following sucking outcome measures were monitored for each feeding: stages of sucking as defined in our earlier study [2], amplitude of the suction component (mmHg), duration of the generated negative intraoral pressure (time t, s), duration of sucking bursts (s), number of suctions and expressions per burst, and total "out" time (s). These parameters were computed from the average of three sucking bursts occurring within the first, second, and last third of the monitored sessions. Each measure was calculated based on a weighted average using the following formula: [T1(B1)+T2(B2)+T3(B3)]/[T1+T2+T3], with T1, T2, T3 corresponding to the duration of the respective sucking bursts and B1, B2, B3 the average of a particular measure within the respective bursts. Sucking bursts were delineated by periods of pause (no sucking) ≥1.5 s. More specifically, a feeding session was divided into three equal time periods. Within each period, durations of all the sucking bursts were measured to compute a mean duration. The sucking burst to be analyzed was selected on the basis that its stage of sucking was representative of that of the majority of sucking bursts within that same period and its duration was closest to the mean duration computed (T1, T2, T3). Within these selected bursts, the average value of each of the defined outcomes, e.g., suction amplitude, was calculated (B1, B2, B3) and its weighted average was computed using the above equation.

Data analyses

Insofar as the rate of milk transfer is positively correlated with the stage of sucking and the strength of the suction component [2,17,18], and that these two factors change as the infants mature, it was deemed appropriate to analyze the effect of different bottle nipples on all the outcome measures within a specific time period, i.e., when infants were taking 1–2 and 6–8 oral feedings/d. A one-way repeated measure analysis of variance was used to compare within time periods. *Post hoc* analyses (paired *t*-test) were conducted when appropriate. Paired *t*-test was used to assess differences within a group between time periods. The percent agreement between caretakers' choice of bottle nipple and the one giving the best rate of milk transfer at each feeding session was calculated as described above. A *p*-level of 0.05 was deemed significant.

Results

Table II shows the ages and weights at which the infants achieved specific oral feeding milestones. The results of all the clinical and sucking outcome measures at 1–2 and 6–8 oral feedings/d are presented in Tables III and IV. When the infants were taking 1–2 oral feedings/d, the rate of milk transfer, overall transfer, burst duration, and total "out" time were not statistically different between the three bottle nipples (Table III). However, sucking stage, suction amplitude, and duration of the generated suction (t) were significantly different (Figures 2–4). At 6–8 oral feedings/d, no difference was observed in any of these outcome measures (Tables III and IV, *p*Figures 2–4). Table IV shows that there was a greater number of expressions than suctions per burst duration for nipples A and B, but not for nipple C at both times, i.e., 1–2 and 6–8 oral feedings/d. The rates of milk transfer at 1–2 and 6–8 oral feedings/d with nipple B were not significantly different (=0.089). Milk leakage, if any, for all infants was <3 ml and not significantly different between nipples at both time periods. The agreement between caretakers' choice of nipple if they were to feed the infants and the one providing the *best rate of transfer* was 0% and 22% at the two time periods, respectively.

Behavioral states fluctuated between drowsiness and quiet alert—two states deemed optimal for oral feeding [13]—and were not significantly different between bottle nipples or infants. The number of episodes of desaturation was similar between nipples A, B, and C, i.e., 9% (4/42 monitored feedings), 16% (7/44), and 14% (6/42), respectively. These events resolved without added therapy or stimulation. In only one case with nipple C was a feeding halted because of

NIH-PA Author Manuscript

NIH-PA Author Manuscript

oxygen desaturation. This particular infant had been weaned from 1/4 l to 1/8 l nasal cannula oxygen just prior to the monitored feeding.

Discussion

Healthcare professionals strive to identify the bottle nipple type that they believe will enhance the bottle-feeding performance of their young patients. Some caretakers will abide by the description provided by the manufacturers, e.g., “premature” nipple. Others will use a trial-and-error approach whereby a variety of bottle nipples will be tested at different feeding sessions. The one providing the best milk intake will be selected as the most appropriate one to use. Customarily, as the infant matures, the choice of nipple is modified. Although it is recognized that bottle nipples differ in physical characteristics, there is no information as to how these properties affect the sucking skills of infants. Thus, the primary goals of the present study were first to identify the nipples commonly used in our nurseries that best enhance the oral feeding performance of VLBW infants as they mature, i.e., when taking 1–2 and 6–8 oral feedings/d, and second, to examine how specific sucking measures are altered with each type of nipple during those times. Secondarily, we compared how often the selection of the bottle nipple by caretakers matched the one that gave the best rate of milk transfer. This was conducted in order to determine whether the criterion(a) they used was constructive.

The observation that rate of milk transfer and overall transfer, at both time periods, were similar between all three nipples suggests that their physical characteristics did not affect the oral feeding performance of the infants. The burst duration and total “out” time were used to reflect the needs infants had to stop feeding for reasons such as burping, coughing, and resting. It was reasoned that if a particular nipple were more difficult to use and led to greater difficulty, such occurrence would be reflected by shorter burst duration and/or greater total “out” times. No such observation was made at either time period, suggesting that the three nipples were equally challenging. This likely resulted from the fact that infants were allowed to feed at their own pace, i.e., they were given control of their own intake rather than “encouraged” to complete a feeding within an allocated time.

At 1–2 oral feedings/d, the stages of sucking, suction amplitude, and duration of the generated negative intraoral pressure were significantly different between bottle nipples. Infants with nipple B not only used a less mature sucking pattern, implying that the suction component was not used as frequently, but also smaller suction amplitude and shorter duration of the generated suction than with nipples A and C. With the knowledge that the hole diameter of nipple B is greater than that of the other two nipples, it appears that infants adapted specific sucking skills in order to maintain a similar milk flow or rate of milk transfer with all three nipples. The observation that infants can use the mature alternation of suction/expression with nipple C while falling back on a more immature pattern, i.e., using the expression component only, with nipples A and B, supports the notion that infants can “fine-tune” their sucking skills. This observation is supported by the studies of Mathew et al. and Qureshi et al., suggesting that infants can regulate milk flow [7,19]. It is recognized that safe and successful oral feeding is dependent on an adequate coordination of suck-swallow-breathe and that the latter matures over time [20–23]. Thus, the degree of such coordination attained by an infant at any given time may determine the rate of milk transfer that he/she can handle safely, e.g., swallow without desaturation and/or aspiration. Based on this premise, we propose that preterm infants can modify their sucking skills in order to maintain a rate of transfer that is compatible with the level of suck-swallow-breathe coordination they have attained at a particular time. This concept is supported by the work of Finan and Barlow [24] who speculate that the sucking motor pattern of infants is under the control of a central pattern generator (CPG). This CPG can adapt to changing environmental conditions via afferent sensory feedback, such as in our case, the degree of coordination of suck-swallow-breathe. Similarly, Craig et al. have proposed the existence of an intrinsic τ-guide in the control of sucking pressure in infants [25]. Recently, they applied the same model in their study of perceptuo-motor control in adults and suggested that the τ-guide principle may be a common process linking various forms of timing in motor function [26]. The lack of difference in sucking variables when infants are taking 6–8 oral feedings per day may result from the maturation of the swallowing reflex and swallow–respiration interfacing. The former become more adaptable, e.g., larger and varying bolus sizes can be handled and the swallowing reflex is swifter as a result of improved coordination of the swallowing musculature [16,27]. At the same time, there is evidence that coordination of suck-swallow-breathe progresses [16]. Indeed, we observed that, as preterm infants mature, swallow–respiration interfacings, i.e., times at which swallowing preferentially occurs in relation to the respiratory cycle, change to favor a safer time to swallow (start or end of inspiration when airflow is halted). Thus, we speculate that the lack of significance in sucking skills between bottle nipples when infants reached 6–8 oral feedings per day reflects not only certain maturational aspects of sucking, but also the increased adaptability of the swallowing process and/or the improved suck–swallow and swallow–respiration interactions achieved with maturation. It is of interest to note that, despite such maturation, our subjects still fell back on using expression only more frequently than the alternation of suction/expression when feeding with nipples A and B versus C. We have made similar observations on full-term and preterm infants who have attained independent oral feeding when flow rate was apparently too fast as evidenced by increased milk leakage (unpublished).

It should be remembered that, by the nature of our exclusion criteria, our subjects are predominantly “healthy”, medically stable VLBW infants whose neurological and pulmonary function are maturing with time. If our theory is correct, it would be expected that infants with neurological impairments or other medical complications, e.g., bronchopulmonary dysplasia, may not demonstrate such a degree of oral feeding adaptability due to impaired afferent sensory feedback or an inability to overcome specific obstacles such as oxygen desaturation. This may explain some of the persistent feeding difficulties encountered by these infants. It is evident that additional studies will be necessary to verify such speculation.

Finally, the poor agreement between caretakers’ choice of bottle nipple and the one providing the *best rate of milk transfer* would suggest that selection of an optimal bottle nipple may not be achievable at present due to our limited knowledge of how infants’ oral feeding skills can be complimented by the physical properties of the nipples. It would also appear that concern over the best bottle nipple to use for a feeding may not be of clinical significance insofar as our subjects were already capable of modifying their feeding skills to maintain a certain rate of milk transfer when taking 1–2 oral feedings/d.

In summary, we did not identify a particular bottle nipple that enhances oral feeding performance. However, we speculate that the choice of bottle nipple may not be an important determinant of the oral feeding performance of healthy VLBW infants. The integrity of their afferent sensory feedback may allow them to modify specific sucking variables in order to maintain an appropriate rate of milk transfer given the maturity level of their suck-swallow-breathe coordination. This study downplays the importance of the selection of an optimal bottle nipple, but stresses the importance of monitoring suck-swallow-breathe coordination by allowing infants to feed at their own pace rather than “encouraging” them to finish a prescribed volume within a specific time period.

Acknowledgements

The authors wish to thank Alicia Thomas and Sandra Fucile, OTR, MS, for their assistance in the collection of the data, S. Fucile, OTR, MS, for her critical review of the manuscript, E. O. Smith, PhD, and Ken Fraley for statistical assistance. This work was supported by grants from the National Institutes of Child Health and Human Development (R01-HD28140), the General Clinical Research Center, Baylor College of Medicine/Texas Children’s Hospital Clinical Research Center (M01-RR-00188), National Institute of Health. Partial funding was also provided from the

USDA/ARS, Children's Nutrition Research Center, and the Department of Pediatrics, Baylor College of Medicine Texas Children's Hospital, Houston, TX. The contents of this publication do not necessarily reflect the views or policies of the USDA, nor does mention of trade names, commercial products, or organizations imply endorsement by the US government.

References

1. American Academy of Pediatrics. Hospital discharge of the high-risk neonate. Proposed guidelines Pediatrics 1998;102:411–7.
2. Lau C, Alagugurusamy R, Schanler RJ, Smith EO, Shulman RJ. Characterization of the developmental stages of sucking in preterm infants during bottle feeding. Acta Paediatr 2000;89:846–52. [PubMed: 10943969]
3. Schanler RJ, Shulman RJ, Lau C, Smith EO, Heitkemper MM. Feeding strategies for premature infants: randomized trial of gastrointestinal priming and tube-feeding method. Pediatrics 1999;103:434–9. [PubMed: 9925837][see comments]
4. Wolff PH. The serial organization of sucking in the young infant. Pediatrics 1968;42:943–56. [PubMed: 4235770]
5. Mathew OP. Nipple units for newborn infants: a functional comparison. Pediatrics 1988;81:688–91. [PubMed: 3357729]
6. Mathew OP. Determinants of milk flow through nipple units. Role of hole size and nipple thickness. Am J Dis Child 1990;144:222–4. [PubMed: 2301329][see comments]
7. Mathew OP, Belan M, Thoppil CK. Sucking patterns of neonates during bottle feeding: comparison of different nipple units. Am J Perinatol 1992;9:265–9. [PubMed: 1627217]
8. Lau C, Schanler RJ. Oral feeding in premature infants: advantage of a self-paced milk flow. Acta Paediatr 2000;89:453–9. [PubMed: 10830459]
9. Wolf, LS.; Glass, RP. Feeding and swallowing disorders in infancy: Assessment and management. Tucson: Therapy Skills Builders; 1992.
10. Ingersoll EW, Thoman EB. Sleep/wake states of preterm infants: stability, developmental change, diurnal variation, and relation with caregiving activity. Child Dev 1999;70:1–10. [PubMed: 10191511]
11. Papile LA, Munsick-Bruno G, Schaefer A. Relationship of cerebral intraventricular hemorrhage and early childhood neurologic handicaps. J Pediatr 1983;103:273–7. [PubMed: 6875724]
12. Mizuno K, Ueda A, Takeuchi T. Effects of different fluids on the relationship between swallowing and breathing during nutritive sucking in neonates. Biol Neonate 2002;81:45–50. [PubMed: 11803176]
13. Als H. A synactive model of neonatal behavior organization: framework for the assessment of neurobehavioral development in the preterm infant and for support of infants and parents in the neonatal intensive care environment. Phys Occup Ther Pediatr 1986;6:3–53.
14. Brazelton TB. The Brazelton neonatal behavior assessment scale: introduction. Monogr Soc Res Child Dev 1978;43:1–13. [PubMed: 752799]
15. Lau C, Sheena HR, Shulman RJ, Schanler RJ. Oral feeding in low birth weight infants. J Pediatr 1997;130:561–9. [PubMed: 9108854]
16. Lau C, Smith EO, Schanler RJ. Coordination of suck-swallow and swallow-respiration in preterm infants. Acta Paediatr 2003;92:721–7. [PubMed: 12856985]
17. Jain L, Sivieri E, Abbasi S, Bhutani VK. Energetics and mechanics of nutritive sucking in the preterm and term neonate. J Pediatr 1987;111:894–8. [PubMed: 3681557]
18. Sameroff AJ. The components of sucking in the human newborn. J Exp Child Psychol 1968;6:607–23. [PubMed: 5686410]
19. Qureshi MA, Vice FL, Taciak VL, Bosma JF, Gewolb IH. Changes in rhythmic suckle feeding patterns in term infants in the first month of life. Dev Med Child Neurol 2002;44:34–9. [PubMed: 11811648]
20. Lau C, Hurst N. Oral feeding in infants. Curr Probl Pediatr 1999;29:105–24. [PubMed: 10202630]
21. Bu'Lock F, Woolridge MW, Baum JD. Development of coordination of sucking, swallowing and breathing: ultrasound study of term and preterm infants. Dev Med Child Neurol 1990;32:669–78. [PubMed: 2210082]

22. Gewolb IH, Vice FL, Schwietzer-Kenney EL, Taciak VL, Bosma JF. Developmental patterns of rhythmic suck and swallow in preterm infants. Dev Med Child Neurol 2001;43:22–7. [PubMed: 11201418]

23. Goldfield EC, Wolff PH, Schmidt RC. Dynamics of oral-respiratory coordination in full-term and preterm infants: I. Comparisons at 38–40 weeks postconceptional age. Dev Sci 1999;2:363–73.

24. Finan DS, Barlow SM. Intrinsic dynamics and mechano-sensory modulation of non-nutritive sucking in human infants. Early Hum Dev 1998;52:181–97. [PubMed: 9783819]

25. Craig CM, Lee DN. Neonatal control of nutritive sucking pressure: evidence for an intrinsic tau-guide. Exp Brain Res 1999;124:371–82. [PubMed: 9989443]

26. Grealy MA, Craig CM, Bourdin C, Coleman SG. Judging time intervals using a model of perceptuo-motor control. J Cogn Neurosci 2004;16:1185–95. [PubMed: 15453973]

27. Buchholz DW, Bosma JF, Donner MW. Adaptation, compensation, and decompensation of the pharyngeal swallow. Gastrointest Radiol 1985;10:235–9. [PubMed: 4029539]

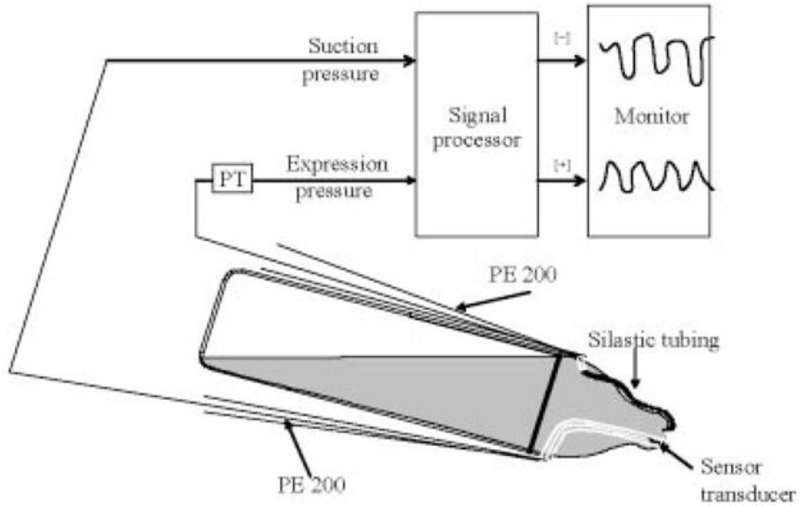

Figure 1.
Schematic of the bottle nipple apparatus for the monitoring of sucking. PT: pressure transducer; PE200: polyethylene tubing.

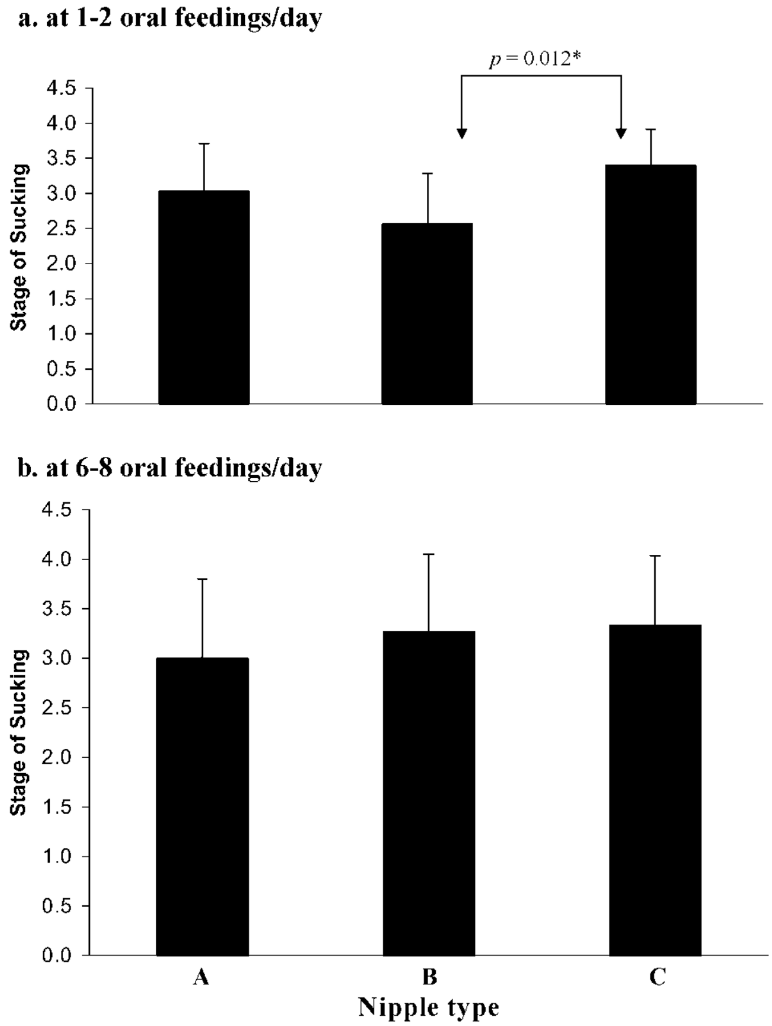

Figure 2.
Stages of sucking by nipple type: (a) at 1–2 oral feedings per day (F=5.442, df=2, p=0.028); (b) at 6–8 oral feedings per day (F=0.751, df=2, p=0.486). *Post hoc significance.

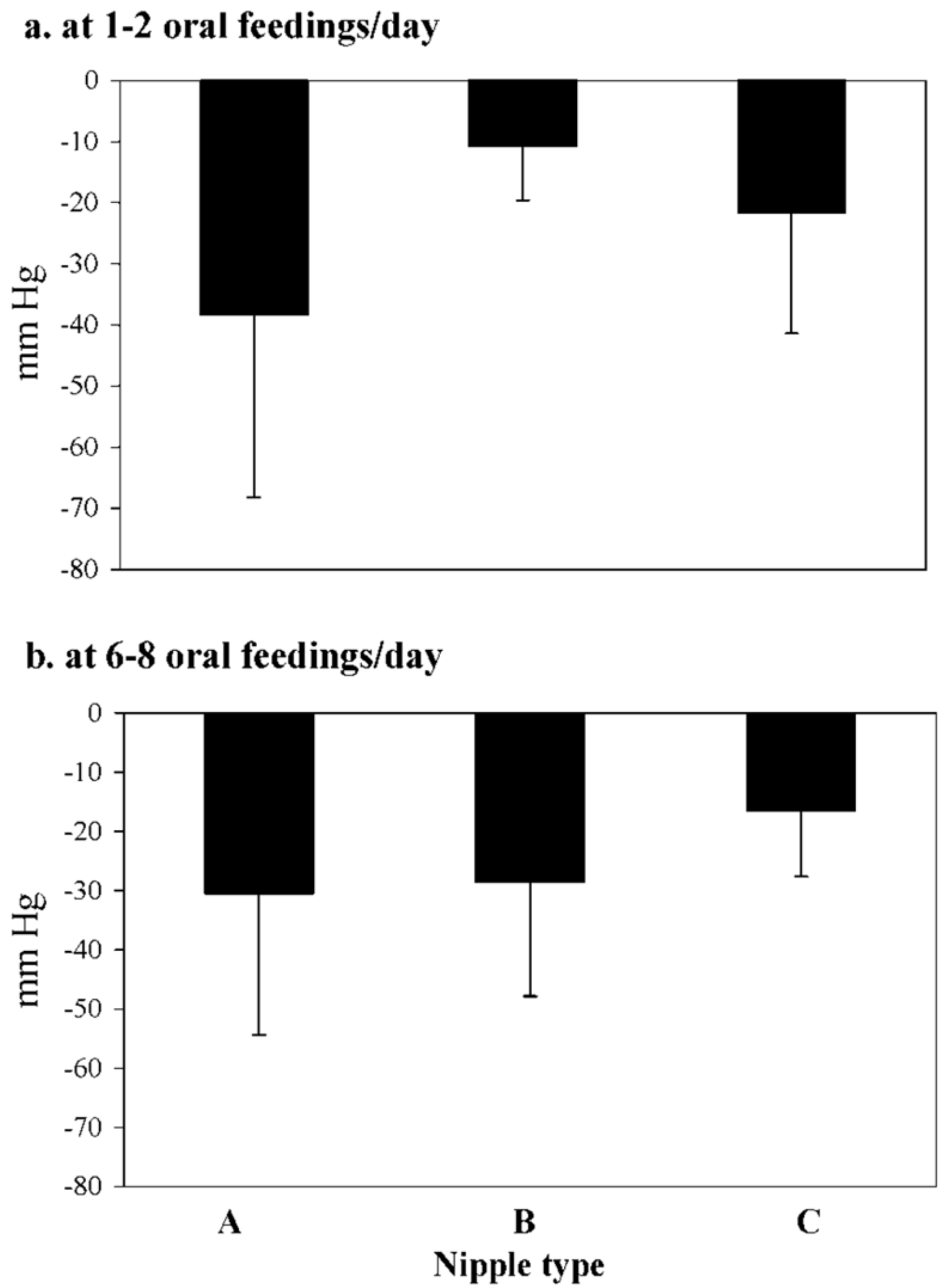

Figure 3.
Suction amplitude (mmHg): (a) at 1–2 oral feedings per day (F=4.170, df=2, *p*=0.033); (b) at 6–8 oral feedings per day (F=2.052, df=2, *p*=0.164).

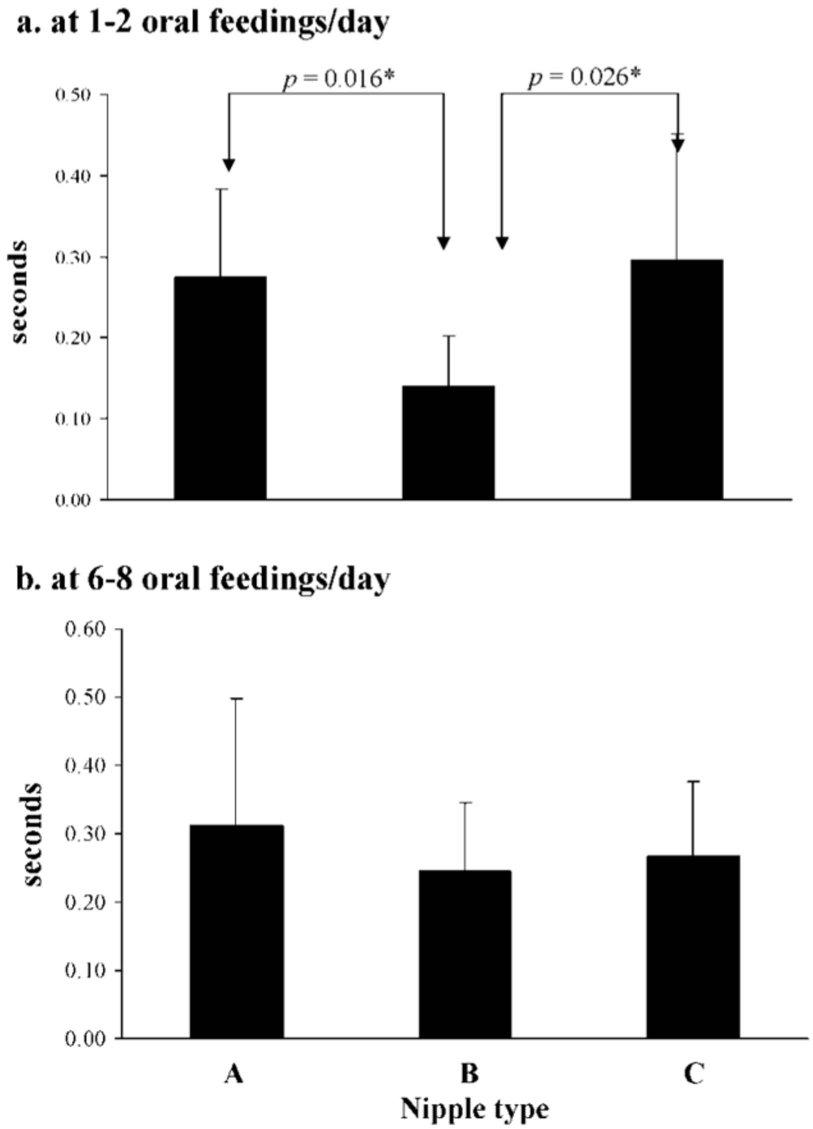

Figure 4.
Duration of generated suction (s): (a) at 1–2 oral feedings per day (F=7.278, df=2, p=0.005); (b) at 6–8 oral feedings per day (F=0.970, df=2, p=0.380). **Post hoc* significance.

Table I

Physical characteristics of bottle nipples.

Description	Nipple A	Nipple B	Nipple C
Relative softness[a]	+ (softest)	+++	++
Relative hole diameter[b]	+ (smallest)	++	+
Additional cross cut	Yes	No	Yes
Relative flow[c]	+ (slowest)	+++	++

[a]Measured blinded by one of the investigators (CES) from an empty nipple.

[b]As provided by the respective manufacturers; holes are laser cut; B is ~29% greater than A and C.

[c]Based on Mathew using a mechanical system to simulate suction [5].

Table II

Infant oral feeding milestones[a]

	Corrected gestational age (wk)	Weight (kg)
Introductioin of oral feedings	33.8±1.6	1.48±0.22
Feeding assessment at 1–2 oral feedings/d	34.8±1.3	1.66±0.21
Feeding assessment at 6–8 oral feedings/d	35.9±1.4	1.95±0.28
Full oral feedings	36.0±1.5	1.99±0.40
Hospital discharge	38.3±2.7	2.22±0.24

[a]Mean±SD.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table III

Outcome measures[a]

	Nipple A	Nipple B	Nipple C	p^b
1–2 oral feedings/d				
Rate of milk transfer (ml/min)	1.5±0.8	1.7±1.2[c]	1.6±0.9	0.639
Overall transfer (%)	78±27	79±25	75±31	0.944
Burst duration (s)	15±7	15±6	21±13	0.123
Total “out” time (s)	112±87	122±45	67±37	0.114
6–8 oral feedings/day				
Rate of milk transfer (ml/min)	1.4±0.9	2.2±1.5[c]	1.5±1.3	0.061
Overall transfer (%)	65±33	77±27	67±36	0.600
Burst duration (s)	11±4	15±10	12±4	0.311
Total “out” time (s)	85±34	77±54	151±129	0.137

[a]Mean±SD.

[b]One-way repeated measures ANOVA.

[c]Paired *t*-test 1–2 vs 6–8 oral feedings/d, p=0.089.

Table IV

Average number of suctions and expressions per burst duration.

1–2 oral feedings/d	**Nipple A**	**Nipple B**	**Nipple C**
No. of suctions/burst duration	10±5	10±7	16±11
No. of expressions/burst duration	15±8[a]	17±6[a]	17±12
6–8 oral feedings/day	Nipple A	Nipple B	Nipple C
No. of suctions/burst duration	9±5	17±24	12±7
No. of expressions/burst duration	13±6[b]	21±25[b]	15±8

[a]Paired *t*-test: $p=0.02$ versus respective no. of suctions/burst duration.

[b]Paired *t*-test: $p \leq 0.01$ versus respective no. of suctions/burst duration.